

REMARKS

Applicants have amended their claims in order to further clarify the definition of various aspects of the present invention. Specifically, claim 3 has been amended at line 4 to recite --anisotropic-- etching, rather than "isotropic" etching. In view of this amendment of claim 3, it is respectfully submitted that the objection to claim 3 as set forth in Item 3 on page 2 of the Office Action mailed December 23, 2003, is moot.

Applicants have amended each of claims 12 and 13 to recite the "increased" curvature, consistent with the understanding by the Examiner as set forth in Item 4 on page 3 of the Office Action mailed December 23, 2003. In view of this amendment of claims 12 and 13, it is respectfully submitted that the rejection of claims 12 and 13 under the second paragraph of 35 USC §112, as set forth in Item 4 on page 3 of the Office Action mailed December 23, 2003, is moot.

Applicants have amended claims 9, 46 and 54 to recite a "selective" thermal oxidation to selectively oxidize the semiconductor substrate (only) at the upper end portion of the trench, consistent with, e.g., recitations in claims 1 and other claims.

In addition, Applicants are adding new claims 56-66 to the application. Claims 56-66, respectively dependent on the independent claims other than claim 54, recite that the chemically mechanically polished surface is formed over the circuit formation surface and over the trench (or trenches, or trench regions, as appropriate), and that in the selective thermal oxidation the semiconductor substrate having the chemically mechanically polished surface formed over the circuit formation region and over the trench (or trenches, or trench regions) is selectively thermally oxidized. In connection with these newly added claims, note, e.g., Fig. 6K and the following figures

in Fig. 6, together with the description at pages 23-25, and, e.g., pages 7, 13 and 14, of Applicants' specification.

In the Office Action mailed July 3, 2003, in the above-identified application, the Examiner contended that the recitation "performing oxidation of said semiconductor substrate having said polished surface" was not supported in Applicants' original disclosure. The Examiner indicated that, at best, pages 7, 13 and 14 of the originally filed specification disclosed that the buried insulating film is etched back by chemical-mechanical polishing or dry etching. However, attention is respectfully directed to, e.g., Fig. 6K of Applicants' original disclosure, particularly together with portions of Applicants' specification referred to previously. Note also Fig. 8K of Applicants' original disclosure. Particularly in view thereof, it is respectfully submitted that Applicants' specification clearly provides a description, and, more specifically, an enabling description, of the performance of selective thermal oxidation of the semiconductor substrate having the chemically mechanically polished surface formed over the circuit formation region and over the trench, such that the presently newly added claims are clearly supported by Applicants' disclosure as originally filed.

Applicants respectfully submit that all of the claims presented for consideration by the Examiner patentably distinguish over the teachings of the references applied by the Examiner in rejecting claims in the Office Action mailed December 23, 2003, that is, the teachings of the U.S. Patent to Mehta, et al., No. 5,646,063, and European Patent Application No. 459 397 (which the Examiner has designated as "Takahashi", and which will be referred to hereinafter by this name), under the requirements of 35 USC §103.

It is respectfully submitted that the references as applied by the Examiner would have neither taught nor would have suggested such a method for fabricating a semiconductor device or semiconductor substrate as in the present claims, including, after forming a trench (trenches) or trench region, thermally oxidizing a trench portion formed in the semiconductor substrate, exposed in the trench, so as to form, e.g., a first curvature of the upper end portion of the trench; and after burying a buried insulating film into the trench and on an oxidation prevention film on a substrate having the trench formed therein, removing the insulating film by chemical mechanical polishing and thereafter performing selective thermal oxidation of the substrate after having formed the chemically mechanically polished surface, so as to thermally oxidize only a portion of the substrate, at the upper end portion of the trench, and not substantially at other portions of the substrate lining the trench, so as to increase a curvature of the upper end portion of the trench substantially without oxidizing the other portions of the semiconductor substrate lining the trench. See claim 1. Note also claims 2, 4, 5, 9, 10 and 15, having corresponding recitations. Note similar recitations in claims 41, 43, 45, 46 and 47.

Moreover, it is respectfully submitted that the teachings of the applied references do not disclose, nor would have suggested, such method of fabricating a semiconductor device, as in the present claims, including forming the trench; thermally oxidizing a trench portion formed in the substrate and burying a buried insulating film into the trench so thermally oxidized, the insulating film also being formed on the oxidation prevention film; after burying the buried insulating film, performing an additional thermal oxidation so as to selectively oxidize the semiconductor substrate at

the upper end portion of the trench, to increase the radius of curvature in the proximity of the upper end portion of the trench, and substantially without oxidizing other portions of the semiconductor substrate lining the trench; and after burying the buried insulating film, removing the insulating film on the oxidation prevention film. See claim 54.

In general, and as will be discussed further infra, it is respectfully submitted that the applied references do not disclose, nor would have suggested, and in fact would have taught away from, the method of fabricating a semiconductor device as in the present claims, including the thermal oxidation of the trench and then, after burying insulation material in the trench, performing additional, selective thermal oxidation to selectively oxidize the semiconductor substrate at the upper end portion of the trench, to increase the radius of curvature at the upper end portion and substantially without oxidizing other portions of the substrate lining the trench.

Furthermore, it is respectfully submitted that these references would have neither taught nor would have suggested the presently claimed method, having features as discussed previously, and; moreover, wherein the trench is provided by a two-step procedure, a first step wherein a shallow trench having a radius of curvature at corners thereof is formed, and thereafter a trench having a predetermined depth to the shallow trench is formed. Note, e.g., claims 2, 5, 43 and 54.

Moreover, it is respectfully submitted that the teachings of the applied references would have neither disclosed nor would have suggested such a method of fabricating a semiconductor device as in the present claims, having features as discussed in the independent claims, and additionally wherein the chemically mechanically polished surface is formed over the circuit formation surface and over the

trench, and wherein in the selective thermal oxidation, the semiconductor substrate having the chemically mechanically polished surface formed over the circuit formation region and over the trench is selectively thermally oxidized. See claims 56-66.

In addition, it is respectfully submitted that the teachings of the applied references would have neither disclosed nor would have suggested the other aspects of the present invention as in the remaining claims, having features as discussed previously, and further including (but not limited to) wherein the step for forming shallow trenches is carried out by isotropic etching and the step for forming trenches having a predetermined depth is carried out by anisotropic etching (see claims 3 and 6); and/or wherein providing the curvature includes forming bird's beaks at the upper end portion of the trench (note claim 12); and/or wherein providing the curvature is performed such that an angle between the circuit formation surface of the semiconductor substrate and a side surface of the semiconductor substrate forming the trench is within a range of  $90^{\circ}$  and  $180^{\circ}$  (see claim 13); and/or material of the buried insulating film and the technique for formation thereof as in claims 18-38; and/or wherein the oxidation prevention film is removed after performing the additional thermal oxidation (see, e.g., claims 39, 42, 44 and 48, as well as claims 49-53).

The invention as presently claimed in the above-identified application is directed to a method of manufacturing a semiconductor substrate, or semiconductor device, having a trench isolation structure. A process forming a so-called "trench isolation structure", which forms trenches extending into the substrate from the substrate surface and then selectively oxidizes the trenches to form a thermal oxide film, has

been employed to form insulating/isolation structure of semiconductor devices, as described in the paragraph bridging pages 1 and 2 of Applicants' specification.

In the trench isolation structure, end portions (corner points) essentially exist near the trench upper end portion of the semiconductor substrate. Stress concentration fields (both mechanical stress and electrical stress) are formed near these end portions. Because such stress concentration fields are formed, the shape of the substrate, particularly near the trench upper end portion, is oxidized in some cases into a pointed shape having an acute angle, as shown by the structure represented by reference character 4 in Fig. 1C of Applicants' original disclosure. If such an acute angle portion 4 remains on the semiconductor surface, however, concentration of electric field occurs at this acute angle portion during circuit operation and deteriorates the breakdown voltage characteristics of, e.g., transistors, capacitors, etc., formed using such substrate. Moreover, mechanical stress fields, which are disadvantageous, are also formed. See the paragraph bridging pages 3 and 4 of Applicants' specification.

Additional problems can arise where trenches are filled with a burying material, such as buried insulating material of chemically vapor deposited silicon oxide, for example. If additional thermal oxidation is performed after burying the buried insulating film, this additional thermal oxidation oxidizing the semiconductor substrate lining the trench, volume expansion caused by the thermal oxidation after filling the trench causes a compressing stress of the semiconductor substrate due to the volume expansion of the filled trench, such stress deteriorating characteristics of electrical devices formed using the substrate.

Against this background, Applicants provide a process wherein trench isolation can be utilized, without causing deterioration of breakdown voltage characteristics of devices such as transistors and capacitors formed using the substrate with the trench isolation structure, while providing semiconductor devices having a high reliability, and wherein compressing stresses on the semiconductor substrate lining the trench are avoided. Moreover, Applicants fabricate the structure using a relatively simple technique.

Applicants have found that the desired structure, avoiding problems as discussed in the foregoing, can be achieved by preventing a substrate shape in the proximity of the upper end portion of the device isolation trench from becoming an acute angle; and, by the present invention, provide simple techniques for preventing such acute angle, while avoiding other problems arising due to stresses in the semiconductor substrate adjacent the trenches. Specifically, according to an aspect of the present invention, Applicants provide procedures which can easily and effectively provide a curvature (increased curvature) only of an upper end portion of the trench, by a selective thermal oxidation which selectively oxidizes only the upper end portion. For example, and specifically, according to aspects of the present invention, after an initial thermal oxidation providing curvature at the upper end portion of the trench, and thereafter burying the buried insulating film, this insulating film also being formed on an oxidation prevention film on the semiconductor substrate, this insulating film on the oxidation prevention film is removed, e.g., by chemical mechanical polishing, leaving the insulating film buried in the trench and, e.g., the structure having a chemically mechanically polished surface over the trench and over a circuit formation surface of

the semiconductor substrate; and the upper end portion of the trench is selectively thermally oxidized while lower portions of the trench (in particular, the semiconductor substrate lining the trench extending from the upper end portion) are substantially not oxidized, whereby the semiconductor substrate can be thermally oxidized (selectively) at only the upper end portion of the trench, and not substantially at other portions of the semiconductor substrate lining the trench.

Removal of the insulating film from the oxidation prevention film, prior to the additional, selective thermal oxidation, can, for example, uncover upper end portions of the trench, facilitating selective thermal oxidation of the upper end portions. As the chemically mechanically polished surface is subjected to the selective thermal oxidation, the insulating film surface over the trench is sufficiently higher than the surface of the substrate such that selective thermal oxidation as in the present claims can easily be achieved; compare with the structure that is thermally oxidized shown in Fig. 7 of Mehta, et al., wherein the burying material surface is relatively close to the surface of the substrate.

Moreover, after burying the buried insulating film and removal of this insulating film from the oxidation prevention film on the substrate, an upper end portion of the trench can be provided with curvature (increased curvature), which prevents the acute angle. Thus, prevention of the acute angle can be achieved, for example, by thermal oxidation of substantially only the upper end portion of the trench, after the initial oxidation and burying, e.g., by forming bird's beaks only at the upper end portion of the trench.



It is emphasized that according to the present invention, two thermal oxidation steps are performed with, e.g., an oxidation resistant film in place, a first prior to burying the trench and a second after burying the trench, the second thermal oxidation being performed as a selective thermal oxidation that oxidizes only upper end portions of the trench. With the two thermal oxidations, particularly wherein the second (additional), selective thermal oxidation thermally oxidizes only upper end portions of the trenches, the aforementioned acute angle can be avoided, while also avoiding undesirable compressing stresses on the semiconductor substrate lining the trenches.

Thus, according to the present invention as claimed in the above-identified application, there are two thermal oxidation steps, with the trench being buried between the first and second thermal oxidation steps. In the first thermal oxidation step, an oxidation film is formed on the surface of the trench, with a curvature to some degree being formed at the upper end of the trench. Since this first thermal oxidation film is formed before the trench is buried, even by carrying out thermal oxidation with volume expansion by oxidizing the trench, since the trench is not filled a compressing stress does not form along the substrate lining the trench, so that deterioration of electrical properties, due to such compressing stress, is avoided.

In the second thermal oxidation step, the additional thermal oxidation is carried out in the condition that an insulating film is buried in the trench; accordingly, only the upper end portions of the trench are selectively thermally oxidized, without thermally oxidizing other portions of the semiconductor substrate lining the trench. Thus, since, e.g., bottom portions and bottom side portions of the trench are not thermally oxidized, deterioration of the properties due to compressing stress can be avoided.

Furthermore, since upper end portions of the trench are selectively thermally oxidized, a sufficient curvature is formed at upper end portions of the trench, avoiding the sharp angle thereat and adverse effects thereof.

Furthermore, according to additional aspects of the present invention, and as discussed previously, by performing selective thermal oxidation of the chemically mechanically polished surface formed over the circuit formation region and over the trench a desired surface for performing the selective thermal oxidation is provided.

That is, as seen in, e.g., Fig. 6K of Applicants' original disclosure, the buried material overlying the trench extends above the surface of the semiconductor substrate, thereby providing a more effective structure for the selective thermal oxidation. Compare with, for example, Fig. 7 of Mehta, et al., wherein the structure subjected to the second oxidation has a recessed upper surface over the trench relative to the surface of the oxidation resistant film 18. It is respectfully submitted that with the structure being oxidized as shown in Fig. 7 of Mehta, et al., having surface 66 relatively close to the substrate, stress occurs due to oxidation of the substrate lining the trench, and/or a gap may occur at the upper end due to, of concentration of stress. Such problems, which can arise in connection with Mehta, et al., would not effectively achieve the results and advantages according to the present invention.

To emphasize, according to various aspects of the present invention including selective oxidation of only upper end portions of the trench in the selective oxidation step, various advantages are achieved, including avoidance of an increase of stress due to compressing stress along the substrate lining the trench, and narrowing of the element formation region due to enlargement of bird's beak at the upper end portions

of the trench. According to the present invention, sufficient curvature is achieved to avoid decrease in electrical properties caused by the sharp angle at the upper end portions of the trench, while disadvantageous narrowing of the element formation region due to undue enlargement of the bird's beak at the upper end portions of the trench can be avoided.

Applicants' original disclosure clearly sets forth advantages according to the present invention, having the two thermal oxidation steps, the oxidation resistant film formation, and etching back the burying insulating film. That is, as is clear according to the specification of the above-identified application, since the buried insulating film 9 (see, e.g., Figs. 6G and 6H of Applicants' original disclosure) has already been formed inside the trench of the silicon substrate 1, especially wherein the insulating film 9 has been removed from on the oxidation prevention film (e.g., at the upper end portion of the trench), oxidation proceeds from near the trench upper end portion 12, and the inside of the trench is hardly oxidized. That is, a longer time is necessary for oxidation seeds to diffuse inside the buried insulating film 9 before reaching the silicon substrate 1 at lower portions of the trench, than when the silicon substrate is directly oxidized. Therefore, oxidation hardly proceeds substantially near the bottom of the trench.

On the other hand, a weak boundary layer of the coupling portion deposited by chemical vapor deposition or sputtering to the trench side walls and the upper surface of the trench exists at the trench upper end portion 12, and oxidation seeds can diffuse at a relatively high rate along this weak boundary layer, and especially where the insulating film has been removed from on the oxidation prevention film. As a result,

oxidation seeds are supplied to the trench upper end portion 12 within a short time, so that only the portions in the proximity of the trench upper end portion 12 are oxidized preferentially and the formation of the radius of curvature at the trench upper end portion 12 is promoted.

Note, for example, the paragraph bridging pages 24 and 25 of Applicants' specification, referring, inter alia, to the first embodiment. See also the paragraph bridging pages 14 and 15 of Applicants' specification, in connection with the first embodiment. See also page 26 of Applicants' specification, in connection with the third embodiment.

Mehta, et al. discloses a fabrication method for creating wide and narrow isolation regions. The method includes steps of selectively providing an etch resist layer over the wide spacing and exclusive of the narrow spacing, etching the semiconductor structure to increase the depth of the narrow spacing to form a narrow trench, growing an oxide liner in the narrow trench and in the wide spacing, providing a trench fill oxide layer over the nitride layer and the oxide liner in the wide spacing and in the narrow trench, and field oxidizing the wide spacing and the narrow trench. See column 2, lines 4-12. Note also column 2, lines 22-32 and 51-53. Note further column 3, lines 5-7. In a specific embodiment shown in Figs. 5 and 6, this patent discloses that after layer 60 is subjected to an oxide etch, structure 12 is subjected to thermal oxidation to grow the oxide in spacing 44 and 46 by local oxidation of silicon techniques. The growing of layers 60 in spacings 44 and 46 provides a deeper insulative region in both regions 24 and 28 of structure 12. Once subjected to thermal oxidation, the insulative material in regions 24 and 28 grows in a direction toward

nitride layer 18 and base 14; and, therefore, providing conventional LOCOS operation on spacings 44 and 46 creates effective isolation regions 24 and 28 for structure 12. See column 5, lines 55-65.

Of particular relevance is the following description set forth in Mehta, et al., at column 5, lines 58-62 (that is, the portion of Mehta, et al. immediately subsequent to that portion of Mehta, et al. referred to by the Examiner in the last paragraph on page 20 of the Office Action mailed December 23, 2003):

“The growing of layers 60 in spacings 44 and 46 provides a deeper insulative region in both regions 24 and 28 of structure 12. When subjected to thermal oxidation, the insulative material in regions 24 and 28 grows in a direction towards nitride layer 18 and base 14”. (Emphasis added).

It is emphasized that according to the teachings of Mehta, et al., in the thermal oxidation after layer 60 has been subjected to oxide etch, layer 60 grows providing a deeper insulative region in both regions 24 and 28, the insulative material in regions 24 and 28 growing, inter alia, in a direction toward base 14. It is respectfully submitted that this disclosure in Mehta, et al., with respect to growth of the thermal oxide towards the base 14, would have neither disclosed nor would have suggested, and in fact would have taught away from, the presently claimed invention, including wherein the selective thermal oxidation is performed to oxidize only a portion of the substrate at the upper end portion of the trench, and not substantially at other portions of the substrate lining the trench, to provide an increase in curvature of the upper end portion of the trench substantially without oxidizing other portions of the semiconductor substrate lining the trench.

It is respectfully submitted that Mehta, et al. has an entirely different purpose from that of the present invention. That is, Mehta, et al. is concerned with providing a narrow trench isolation region and a wide LOCOS isolation region, for eliminating or reducing dishing due to different widths of trench isolation regions. In contrast, the present invention is directed to avoiding deterioration of electrical properties due to sharp angles and/or stresses arising with trench isolation, including stresses caused by growth of thermal oxide along the trench lines after filling the trench. Particularly noting the purpose of Mehta, et al., including the purpose of growing the insulative material in a direction toward the base (that is, along the trench liner, after filling the trench), as described in column 5, lines 55-65, this patent would have taught away from the present invention.

The contention by the Examiner that Mehta, et al. discloses performing oxidation so as to oxidize only a portion of the semiconductor substrate at the upper end portion of the trench, and not substantially at other portions of the semiconductor substrate lining the trench, is respectfully traversed. Again, it is emphasized that Mehta, et al. specifically discloses thermal oxidation to grow the insulative material in regions 24 and 28 in a direction towards base 14, and provides a deeper insulative region. Such disclosure would have taught away from, and clearly would have neither disclosed nor would have suggested, performing oxidation so as to oxidize only a portion of the substrate at the upper end portion of the trench, as in the present invention.

Applicants respectfully traverse the conclusion by the Examiner in Item 3) on page 20 of the Office Action mailed December 23, 2003, that Mehta, et al. teaches selective thermal oxidation that only oxidizes the upper end portion of trench 44 and

not other portions of the semiconductor substrate lining the trench. Again, attention is respectfully directed to the above-quoted description from Mehta, et al., set forth at column 5, lines 58-62 of Mehta, et al. Clearly, Mehta, et al. describes that the isolative material grows in a direction toward, inter alia, base 14. Clearly, Mehta, et al. would have taught away from the presently claimed invention, including wherein the selective thermal oxidation is performed substantially without oxidizing the other portions of the semiconductor substrate lining the trench, and advantages thereof as discussed in the foregoing.

The contention by the Examiner on page 21 of the Office Action mailed December 23, 2003, that Applicants fail to identify which portions of Mehta, et al. would have taught away from the present invention as claimed, is noted. As is clear from the foregoing, as well as from, for example, pages 38 and 39 of the Submission Amendment) filed November 3, 2003, the disclosure in Mehta, et al., of the insulative material growing in the direction toward base 14 would have taught away from the presently claimed method, including the selective thermal oxidation substantially without oxidizing portions of the substrate lining the trenches, and advantages thereof as discussed in the foregoing (that is, for example, avoidance of stress and degraded characteristics due thereto).

It is respectfully submitted that the additional teachings of Takahashi would not have rectified the deficiencies of Mehta, et al., such that the presently claimed invention as a whole would have been obvious to one of ordinary skill in the art.

Takahashi discloses a method of fabricating a semiconductor device in which device isolation is made by a trench formed in a semiconductor substrate, the method

including a first step of forming a device-isolating trench with a taper at an upper portion thereof, in a semiconductor substrate; and a second step of forming an oxide film on an inner wall of the trench and a surface of the semiconductor substrate near the trench. See the paragraph bridging columns 1 and 2 of Takahashi. Note also column 2, lines 53-58; column 3, lines 7-12, 17-25, 35-39 and 41-46; and column 4, lines 39-54.

Even assuming, arguendo, that the teachings of Takahashi were properly combinable with the teachings of Mehta, et al., such combined teachings would have neither disclosed nor would have suggested the presently claimed subject matter, including the selective thermal oxidation which thermally oxidizes only a portion of the substrate, at the upper end portion of the trench, and not substantially at other portions of the semiconductor substrate lining the trench, so as to increase a curvature of the upper end portion of the trench substantially without oxidizing the other portions of the semiconductor substrate lining the trench, and advantages thereof as discussed in the foregoing; and/or the other aspects of the present invention as discussed in the foregoing, and advantages thereof.

The additional contention by the Examiner in Item 3) on page 20 of the Office Action mailed December 23, 2003, that Mehta, et al. teaches that the thermal oxidation is performed after the chemically mechanically polished surface 66 has been formed, is noted. It is respectfully submitted, however, as described at column 5, lines 46-54 of Mehta, et al., the top surface 66 of layer 60 in spacing 44 and the top surface 68 of layer 60 in spacing 46 are further etched by an oxide etch selective to nitride, such as a wet etching technique, RIE technique, plasma etch or other etching process. In view



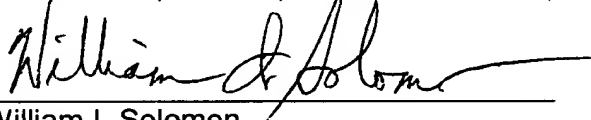
thereof, it is respectfully submitted that Mehta, et al. would have neither taught nor would have suggested, and in fact would have taught away from, selective thermal oxidation of the substrate having the chemically mechanically polished surface as in, for example, claims 56-66; and/or, more generally, wherein selective thermal oxidation of the semiconductor substrate is performed after having formed the chemically mechanically polished surface, as in the present claims.

In view of the foregoing comments and amendments, reconsideration and allowance of all claims remaining in the application are respectfully requested.

To the extent necessary, Applicants petition for an extension of time under 37 CFR §1.136. Please charge any shortage in the fees due in connection with the filing of this paper, including extension of time fees, to Deposit Account No. 01-2135 (500.36904X00) and please credit any excess fees to such deposit account.

Respectfully submitted,

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A handwritten signature in black ink, appearing to read "William I. Solomon", written over a horizontal line.

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